Flight Performance of TOPEX/POSEIDON Star Trackers

David J. Flynn, Walter Fowski
Hughes Danbury Optical Systems

Tooraj Kia
Jet Propulsion Laboratory
California Institute of Technology

Acknowledgments

- Paul Sanneman, Chuck Gay, Ray Welch, Fairchild Space Co.
- Allan Chow, Jet Propulsion Laboratory, California Institute of Technology
- Frank Kissh, Bob McGuffy, Rene Abreu, Hughes Danbury Optical Systems

Flight Performance of TOPEX/POSEIDON Star Trackers

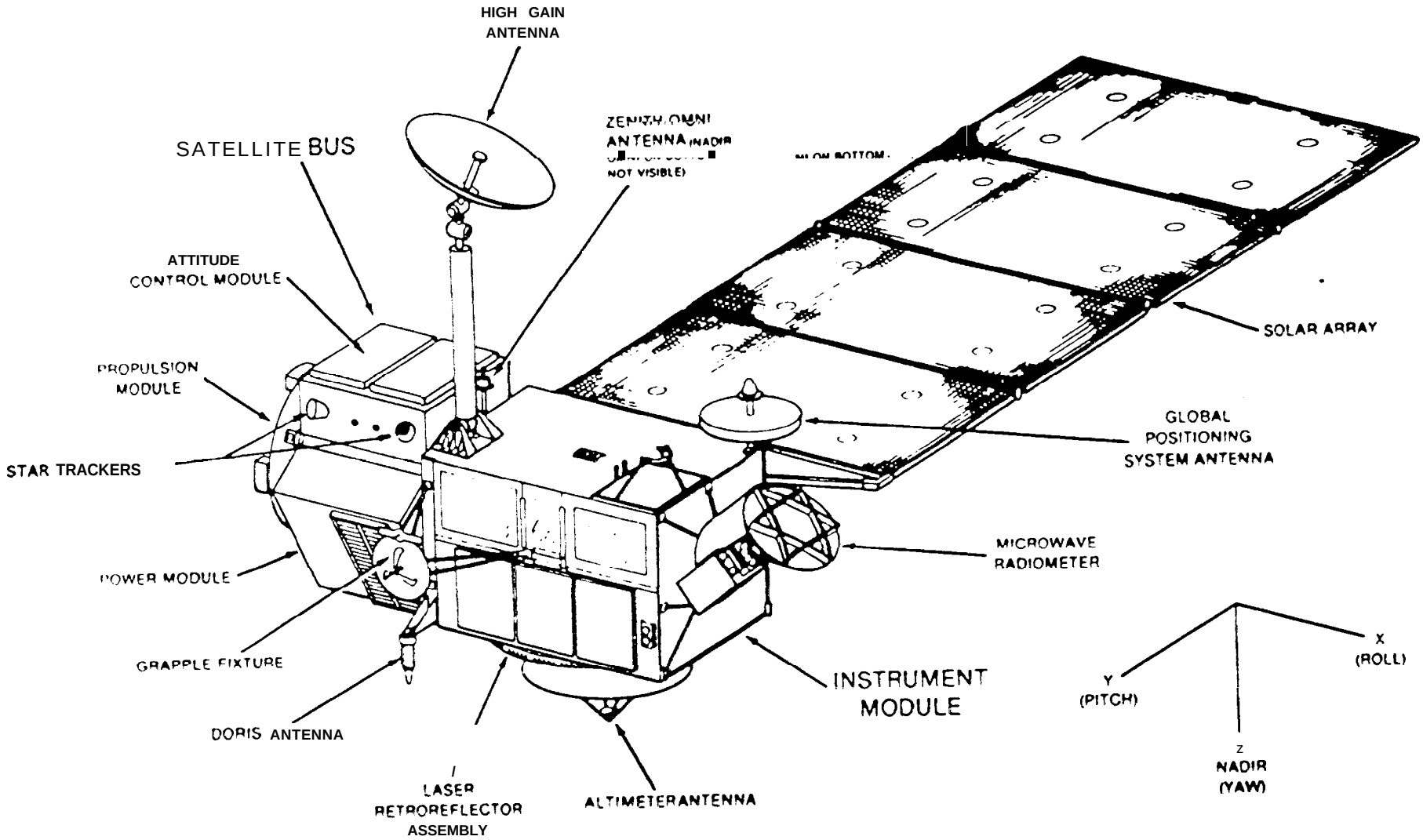
- Mission Overview
- Summary of On-Orbit Operations
- ASTRA-B Anomaly
- ASTRA-A Performance Assessment
  - Position Accuracy
  - Magnitude Accuracy
  - SAA Proton Rejection
- Conclusions

Mission Overview

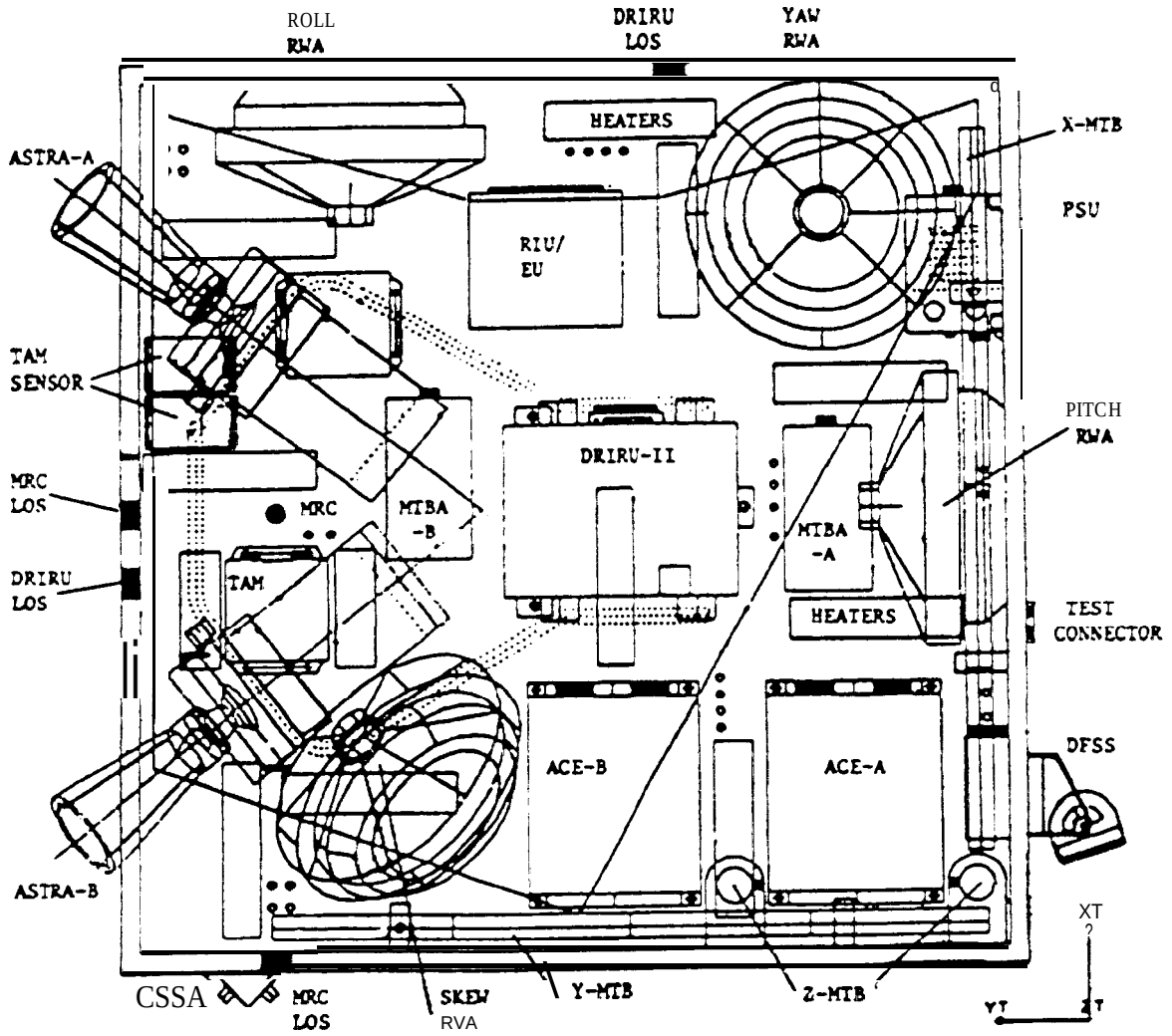
- **TOPEX/POSEIDON is joint NASA/CNES Mission managed by JPL.**
- The objective is **accurate** measurement of **global sea levels over a 3 to 5 year mission life** to **increase our understanding of:**
  - **Ocean dynamics**
  - **Heat and nutrient transfer**
  - **Effect on global climate**
- **Measurements to an accuracy of ± 14cm are made using 2 accurate NADIR-pointing altimeters - a NASA radar altimeter and a CNES Solid State altimeter.**
- **Precise orbit and attitude knowledge are required to achieve these mission** objectives. **Attitude Determination System residual errors (1a) of**
  - **54 arc-see in pitch/yaw**
  - **252 arc-see in roll**

  dictate the local accuracy of IRU, DFSS, and two Star Trackers.
- **Hughes Danbury Optical Systems provided the two Star Trackers via a subcontract to Fairchild Space, the prime contractor.**

TOPEX/POSEIDON Spacecraft



Fairchild's MMS MACS Module



ASTRA TOPEX Star Tracker

- ASTRA is a direct replacement solid-state upgrade, for the NASA Standard Fixed Head Star Tracker
- Key Features
  - Space qualified, radiation hardened system is designed to withstand a three year life in a Van Allen Belt orbit, 1334 km, 66° inclination (RDM = 2)
  - Transient event discrimination algorithms allow robust operation in a worst case, South Atlantic Anomaly, environment
  - Thermoelectrically cooled, backside illuminated CCD provides high signal/noise throughout operational life
  - Microprocessor, 80C86, based system allows flexible autonomous operation and extensive built-in test capability
  - Wide field-of-view, 7°x9°, optics and sensitivity down to visual magnitude 5.7 provide a high probability of multiple stars in the sensor field of view

Summary of On-Orbit Operations

8/10/92 TOPEX/POSEIDON Satellite launched from Kourou, French Guiana, aboard Ariane 42P launch vehicle

- 1334 km, 66° circular orbit
- 112 minute orbital period
- AH systems nominal

11/26/92 ASTRA-B star tracker exhibits an abrupt change in output, no longer tracks stars

12/8/92 Initial system calibrations complete, science data collection in progress

12/16/92 Magnitude threshold adjustment increases percent of stars identified

2/26/93 Science verification workshop completes its favorable evaluation of system performance

ASTRA-B Anomaly

- After 108 days of operation, ASTRA-B abruptly ceased proper operation during SAA exposure and would not exit a Bright Object/Shutter closed test mode

- Analysis of orbital data available indicated
  - CCD response normal
  - TEC/thermal control normal
  - Data interface operational
  - Unit temperature (power consumption) normal

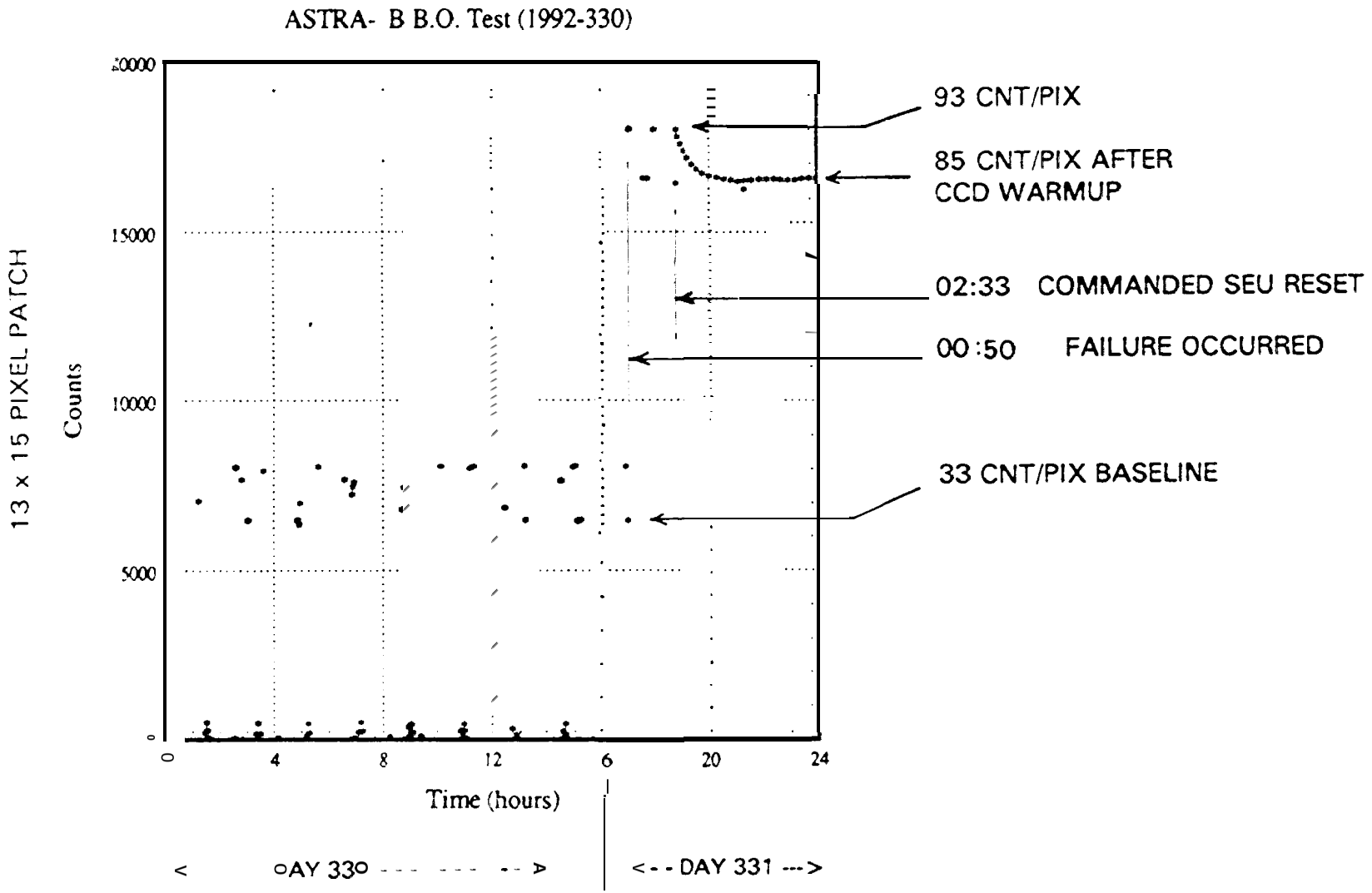
- Passage of moon through FOV indicated inverted mode response from A/D converter. Subsequent failure analysis identified AD9048 A/D converter output mode change from "Binary" to "Inverted Offset Twos Complement".

- Cause of mode transfer currently unknown
  - Random part failure
  - SAA induced latch-up of bipolar device

- JPL evacuating plan to power-cycle ASTRA-B and potentially regain full operating capability

- ADS operating normally with 2 of 3 celestial sensors

DESCRIPTION OF CONDITIONS AT TIME OF FAILURE



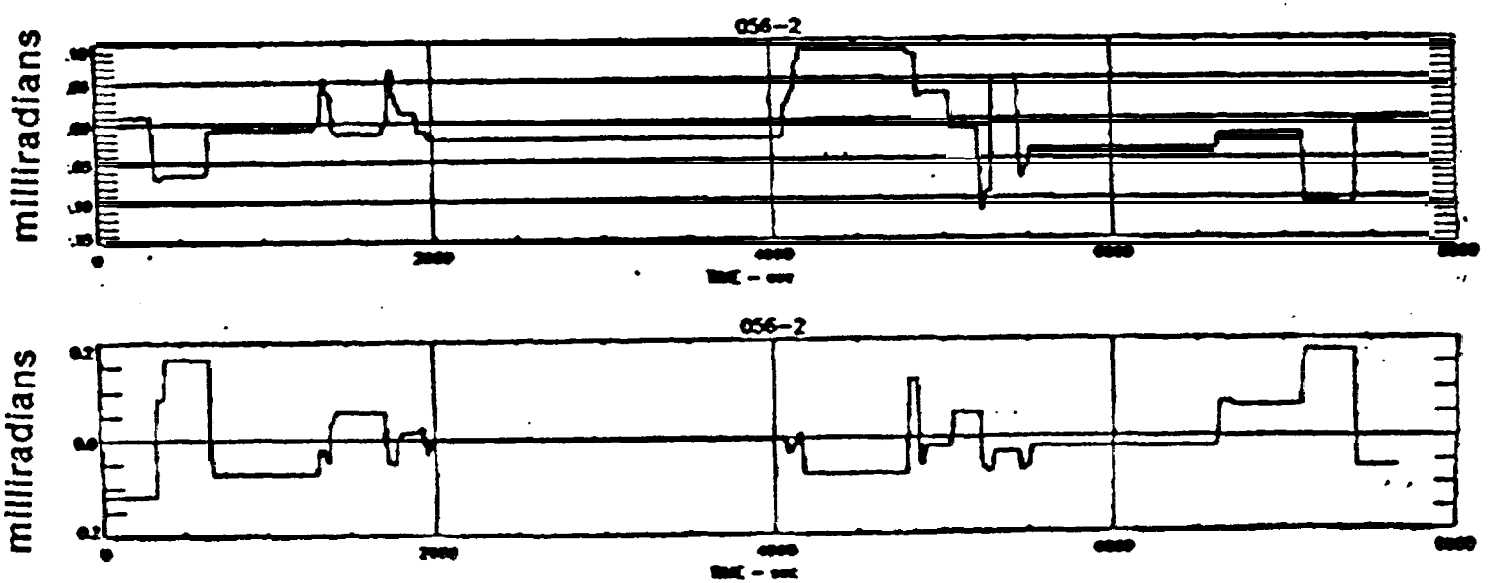
TOPEX Star Tracker Performance Requirements

- **Requirements**
  - Update Rate: 10 hz
  - LOS Motion of stars: c 0.3 degrees/sec
  - Accuracy wrt Indicated Null: < 16.6 arcsec 1σ (mv5, 6000°K / -20°C - 40°C)
  - Boresight Stability: c 120 arcsec peak (-20°C - 40°C)
  - Magnitude Accuracy: ± 0.25 magnitudes (mv 2 to mv 5)
  - Power: < 25 watts (peak)
  - Weight: c 20 lb
  - Radiation Tolerant, including proton events

Position Accuracy: On-Orbit Results

On-Orbit Residual Error Estimate

- ASCAL software is used to estimate
  - alignment between star tracker, gyros, and digital fine sun sensor
  - gyro scale and bias
  - initial attitude of spacecraft
- Residual errors between measured star positions and predicted star positions after calibration: c 40 arcsec peak

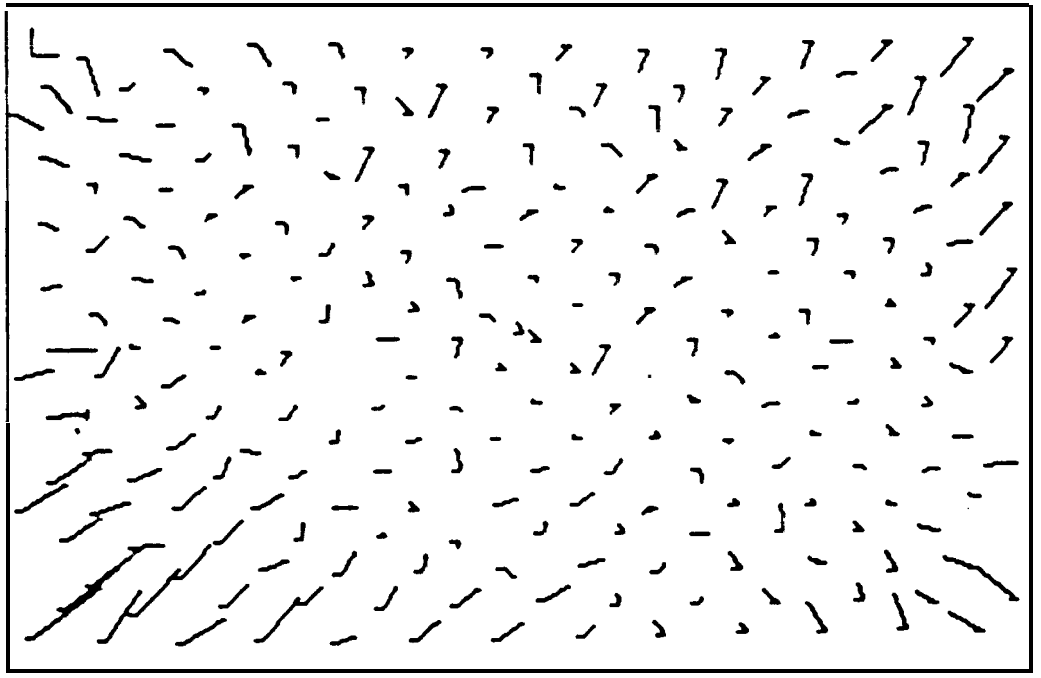


Position Accuracy: Ground Test Results

Beginning of Life Test Results: mv5 G0V star, 20° degree ambient

- Error with respect to indicated null:< 6.5 arcsec 1σ per axis for mv5 GOV star
- Noise Equivalent Angle: < 5 arcsec 1σ per axis

0,0 \TOPEX\FLIGHT\GROUND\D1220125 .002 8,403



LSFCAL.BAS
$Revision: 1.8 $
84-83-1993
H(1) = 1.773D-05
H(z) = -5 .333D-06
H(3) = -7.999D-01
H(4) = 40615.00
H(S) = 0.000D+00
H(6) = 0.000D+00
H(7) = 0.000D+00
H(8) = 0.000D+00
H(9) = 0.000D+00

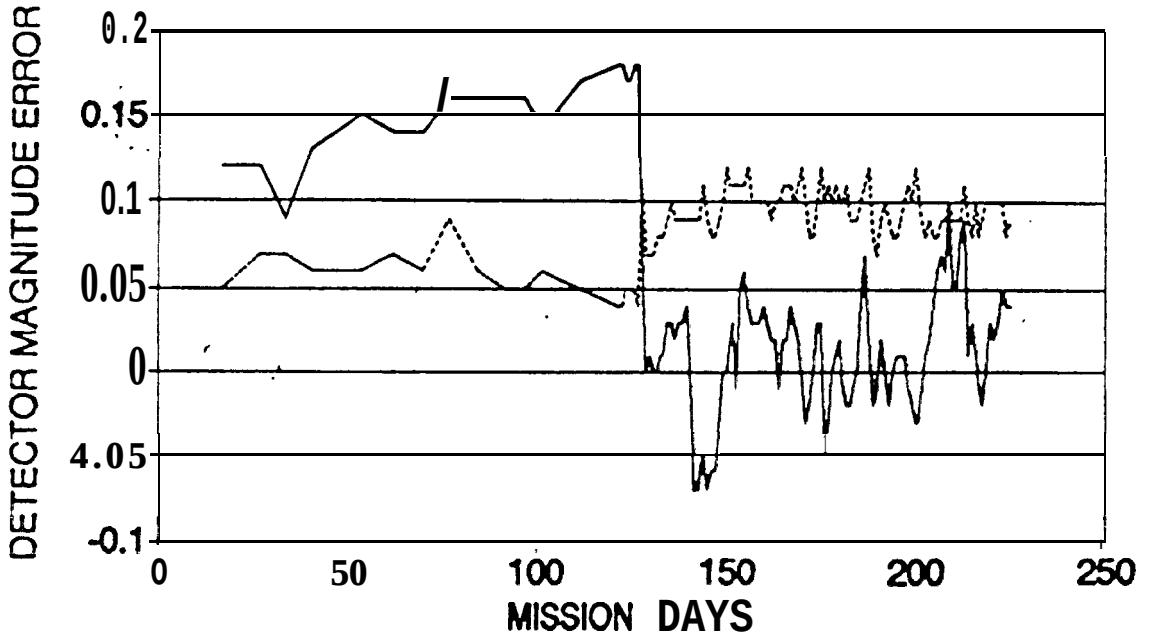
2s6,0 RMS ERROR (SEC)= 8.81 256,483
RMS/MAX ERROR(R, C)= 6.03/ 18.95 6.42/-27.72
NEA RMS/MAX (R,C) (SEC)= 4.11/10.35 4.68/ 9.34
ANALOG AVG,STD (CNTS)= 71.60 4.29

Magnitude Accuracy: On-Orbit Results

Magnitude Trend Results:

- Up to mission day 128 many stars were rejected by the star identification filter due to a magnitude bias error, skewing magnitude statistics. Star identification thresholds have been offset by 0.25 magnitude to account for the bias error. Trending continues to determine if the bias is time dependant.
- There is no obvious correlation between magnitude bias error and star color or magnitude.

Error in Measured Detector Macroitude



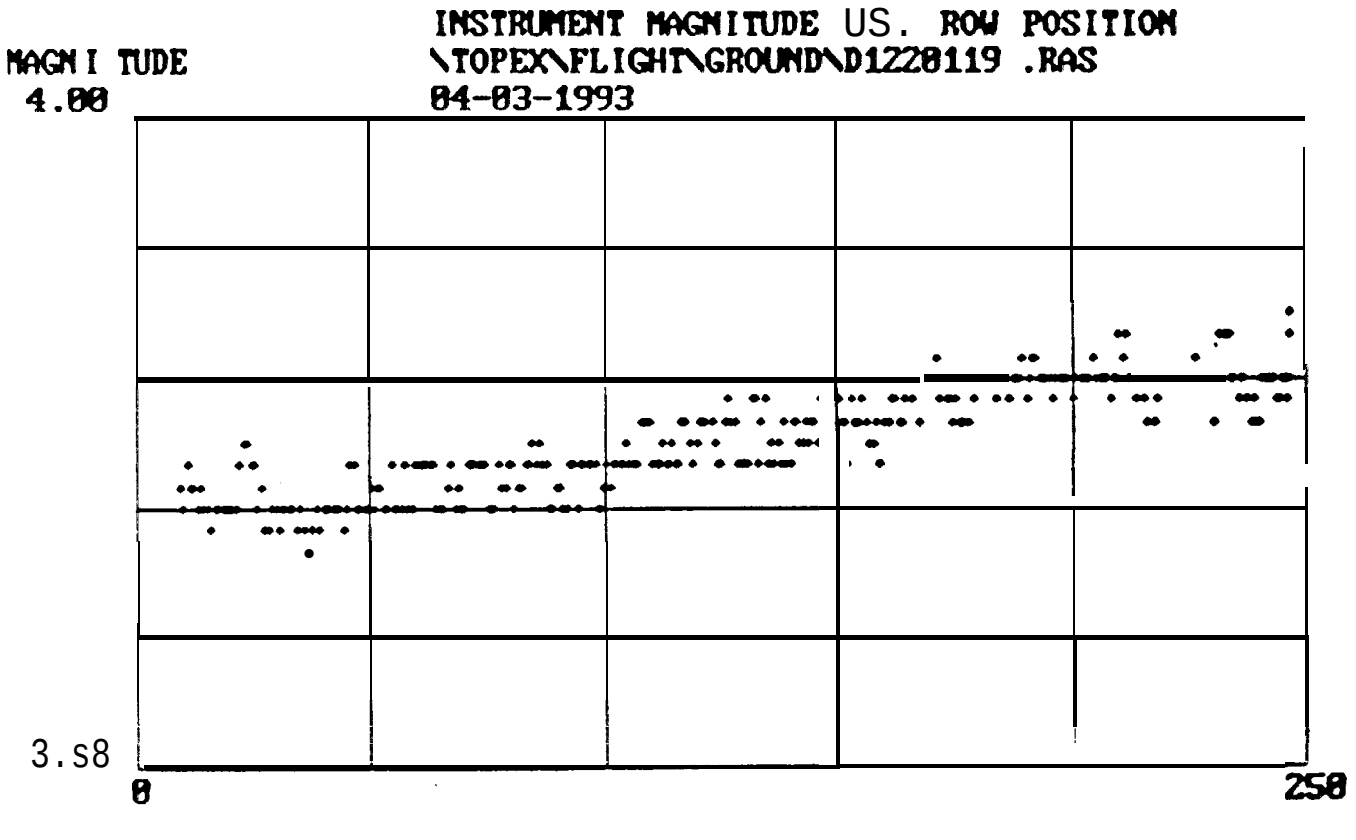
--- 1σ
— mean

note: errors are averaged over all stars identified during a 24 hour period

Magnitude Accuracy: Ground Results

Beginning of Life Test Results: mi 3.8,6000 K star, 20° ambient, 0.3 deg/sec

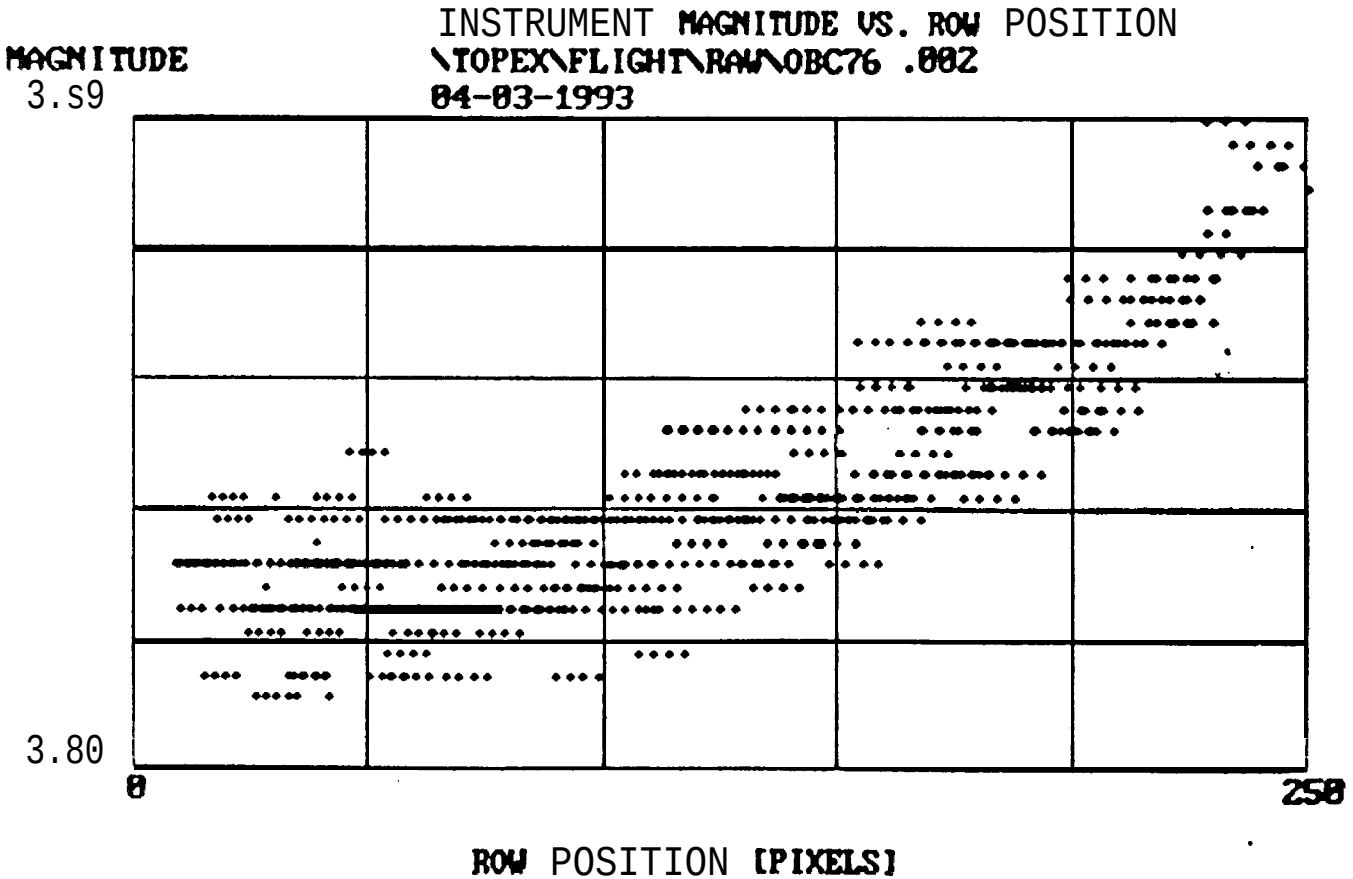
- **Stability over Field: 0.04 magnitude 10,0.18 magnitude peak-peak**
- **Estimated error in absolute calibration: 0.17 magnitude**



Magnitude Accuracy: On-Orbit Results

On-Orbit Results: mi 2.9,4370 K star

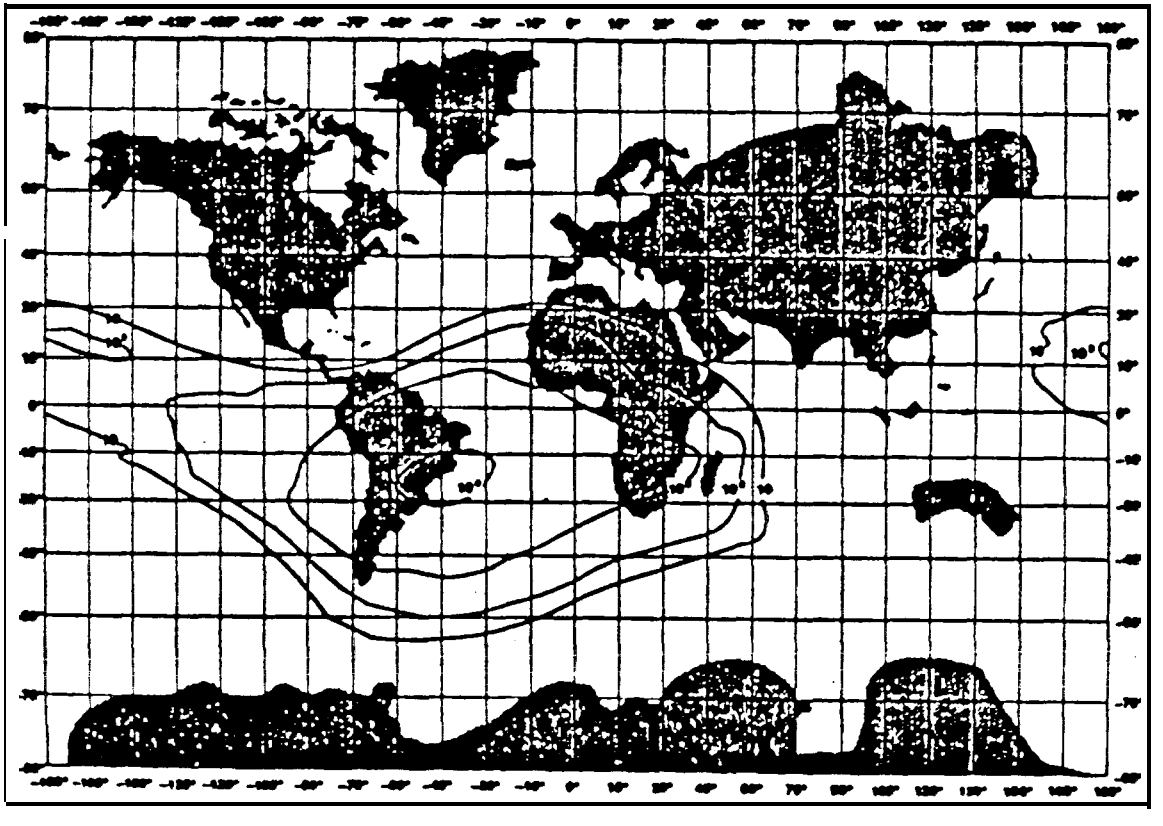
- **Stability over Field: 0.(?85 magnitude 1σ, 0.44 magnitude peak-peak**
  - field dependant magnitude errors dominate
- **Bias Error: 0.28 magnitude**



TOPEX/POSEIDON Star Tracker is Required to Operate in a Severe Radiation Environment

- In order to meet science goals a high inclination, 66°, orbit which passes through the South Atlantic Anomaly (SAA) is required.

PROTON FLUX CONTOUR PLOT
FOR ENERGY E> 20 MeV



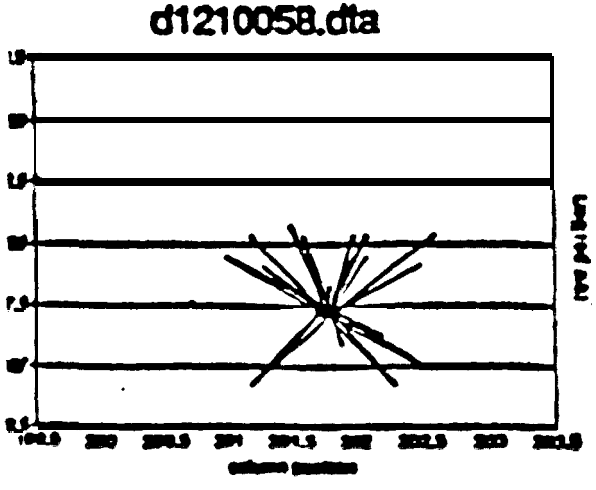
10"4 protons/(cm^2•sec) peak

Star Tracker Operation in a High Density Proton Field

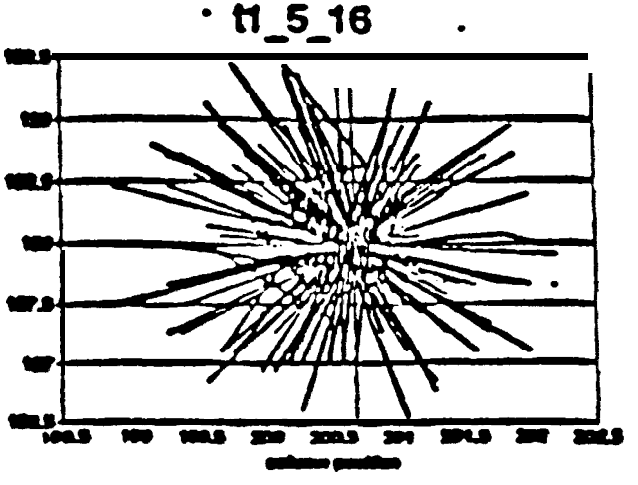
- A unique feature of the TOPEX star tracker is its ability to operate in a high density proton field
- In addition to long term degradation effects and SEU/SEL problems, proton events can result in anomalous sensor operation
  - erroneous acquisition of "false" stars caused by transient events
  - failure to acquire valid stars
  - loss of track of valid stars
  - corrupted position and magnitude data
- Key requirements
  - acquire and track stars with up to 150 transient events per frame
  - 95% probability of acquiring a valid star within 22 seconds
  - identify and alert host if data has been corrupted by a transient event

Transient Event Discrimination: Ground Test Results

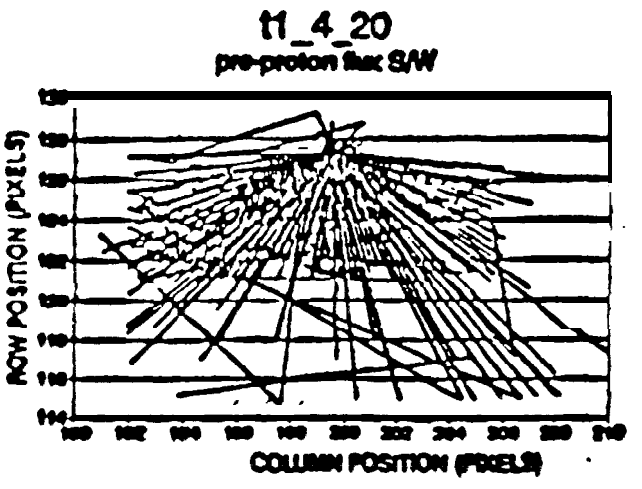
- Using a CRT scene simulator an end-to-end test of the sensor operation with 150 'transient event per frame was performed
- Key Results
  - no acquisitions of false stars (transient events)
  - acquisition of valid stars within 7.11 seconds average, 43.11 second 3σ
  - no loss of track for valid stars
  - successful identification of transient corrupted data



magnitude compare and spatial windowing enabled



magnitude compare disabled



magnitude compare and spatial windowing disabled

Transient Event Discrimination: On-Orbit Results

- Data from other sensors aboard TOPEX/POSEIDON have experienced an increase in the number of transient events while passing through SAA
- ASTRA-A has successfully acquired and tracked stars throughout SAA
- Preliminary analysis of flight data indicates no performance degradation or anomalies while operating in SAA
- Flex data format, update every 64 millisec, is now available allowing frame to frame analysis of performance in SAA

Conclusions

- TOPEX/POSEIDON mission attitude determination objectives are being met
- Position accuracy reported by star tracker is better than 40 arcsec 3 peak, including ASCAL estimation errors
- Magnitude stability over field of view is better than 0.22 magnitude 3σ
- Star Tracker operates properly throughout South Atlantic Anomaly
- ASTRA-III is in an anomalous operating mode, potentially recoverable through power-cycling